# ELECTRICAL PROPERTIES OF CIGS-SOLAR CELL WITH GRADED BAND GAP

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**Abstract**:- CIGS-based thin film module technology has all opportunities to compete with crystalline silicon. The cells under study differ on open circuit voltage Voc. but not so much in their ‘optical’ properties (light current Jsc, quantum efficiency QE(λ). On the other hand, they do differ in their ‘electrical’ properties, both empirical (apparent shunt conductance $G_{sh}$, fill factor FF) and physical (diode ideality n, diode saturation current $J_o$ and built-in potential). The results point to the conclusion that the cell behaviour is determined by the larger than unity n value and to a minor extend, by shunt-conductance but series-resistance hardly has any influence. Further using a non-uniform Ga/In ratio throughout the film thickness, additional fields can be built into p-type CIGS based solar cells, which can enhance performance. It has been shown that the positive gradient structure has the highest current density and the lowest open circuit voltage due to enhanced charge carries collection efficiency and optimized recombination profile. The reverse gradient structure has the maximum overall efficiency and open circuit voltage due to higher potential barrier at the heterointerface, but the lowest current density.

**Introduction**: Copper indium diselenide (CIS) is a p-type multi-crystalline semiconductor with high optical absorption coefficient. For thin film solar cell applications, this compound is used in a hetero junction structure, commonly with a very thin n-type cadmium sulfide (CdS) layer. Pure $CuInSe_2$ has a band gap of 1.04eV. To increase the band gap of absorbing material, indium can be partially replaced by gallium, thus obtaining copper indium gallium diselenide (CIGS). The band gap of pure $CuGaSe_2$ (CGS) is 1.67eV [2].

Copper-Indium-Gallium-Diselenide [$CuIn_{1-x}Ga_xSe_2$ commonly abbreviated as $Cu(In,Ga)Se_2$ or [CIGS] has become one of the most important materials in developing polycrystalline thin film solar cell structures. CIGS has the highest reported absorption coefficient of 3.6 x $10^5 cm^{-1}$. The band gap variation for $CuIn_{(1-x)}Ga_xSe_2$ is given by

$$Eg = 1.011 + 0.664x - 0.249x (1-x).$$

When a solar cell is exposed to a solar spectrum, the photons with energy greater than Eg are absorbed and the material transmits those with energy less than Eg [3]. Hence if we know the energy band gap of the semiconductor then we can find the wavelength range of light that will be absorbed by the semiconductor using the equation.

$\lambda = 1.24 / Eg$. where Eg is in eV and $\lambda$ is in microns. **Band Gap Grading in CIGS Solar Cells**: Using a non-uniform Ga/In ratio throughout the film thickness, additional fields can be built into p-type CIGS based solar cells, and some researchers have asserted that these fields can enhance performance. The study of band gap grading in solar cells based on numerical modeling also suggests the same [1]. The experimental evidence that grading improves device performance, however, has not been compelling, mostly because the addition of Ga itself improves device performance and hence a consistent separation of the grading benefit has not always been achieved [4]. Backgrading in CIGS solar cells is seen to improve simulated device efficiency compared to ungraded devices.

**Electrical Properties**: According to the standard diode equation. the J(V) characteristic of a single-junction solar cell under illumination can be written as the linear superposition of the dark characteristics of the cell and the photogenerated current:

$$J(v) = J_0\left(\exp\left(\frac{q(V - R_S I)}{nKT}\right) - 1\right) + G_{sh} V - J_L$$

Where, $J_o$=Saturation current, q = Elementary charge, V = Photovoltaic voltage, $R_s$= Series resistance, I = Current, n= The ideality factor with n = 1 standing for ideal p-n junctions, whereas n=2 stands for p-i-n junctions, k= Boltzmann's Constant, T= Absolute Temperature, $G_{sh}$ = Shunt conductance, $J_1$ = Photogenerated current.

In the dark, some of these parameter can also be deduced from the log J-V curve. Under illumination we also used n and $J_o$ values from the log $J_{sc}$-$V_{bc}$ curve, and compared these to the curve-fitted values [5].

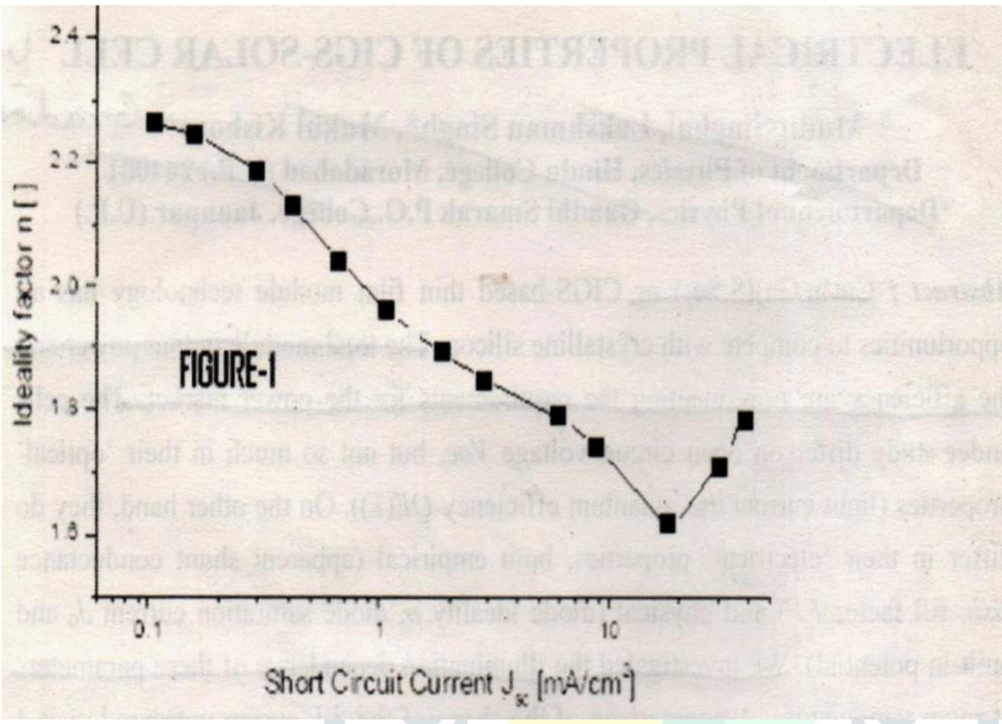


**Figure – 1 : Shows the Variation of Short Circuit Current Density by the Variation of Ideality Factor (n).**

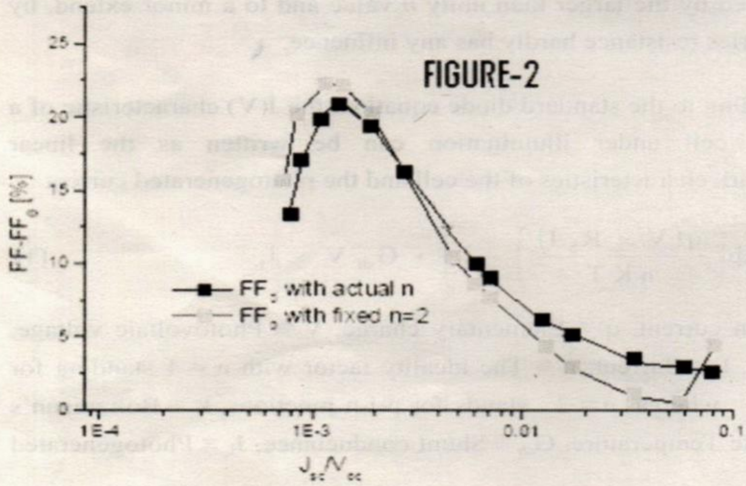


***Figure – 2 :*** **Shows Fill Factor Loss of (FF Measured, and $FF_0$ Calculated) as a Function of Jsc/Voc (Each Point is from a J-V Curve at One Illumination).**

**Conclusion**: Back-grading in CIGS solar cells show small effect for standard thickness (around 0.5%) but gain increases significantly for reduced thickness ($\Delta\eta$=+2%). Double-grading shows benefits similar to those from back- grading, but the additional front-grading can lead to large losses in FF and $J_{sc}$, if the band gap minimum is not contained within the space charge region. Further an extensive room temperature study points to: no appreciable influence on cell parameters determined by a rather high diode non-ideality factor (n), no other non-idealities factor seems to govern $V_{oc}$. and the dependency of (n) on the illumination intensity and the cross-over behavior.

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